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THE NANTUCKET PINE MOTH

A Literature Review

by
Harry
O.
Yates III

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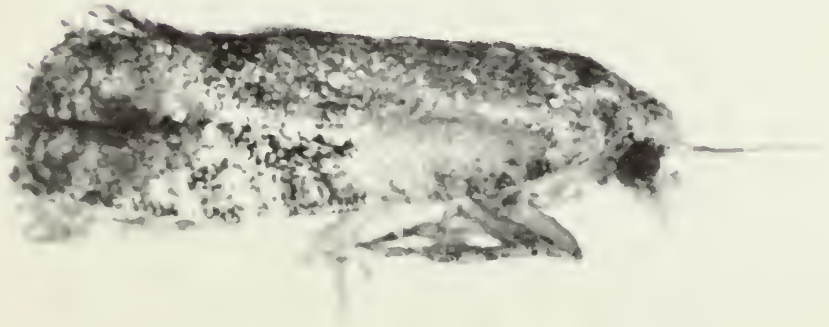

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THE NANTUCKET PINE MOTH *Rhyacionia frustrana (Comst.);* A LITERATURE REVIEW

by
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INTRODUCTION

With the establishment of large areas of pine plantations, the Nantucket pine moth (*Rhyacionia frustrana* (Comst.)) has become more and more abundant and has caused greater and greater concern. Paradoxically, this concern for the most part is confused by the large amount of conjecture about the damage this insect actually inflicts.

Some researchers contend that damage inflicted by the Nantucket pine moth is transitory, representing only a temporary loss of height growth, and that control efforts are not warranted. Most published material does not support this contention. For example, Korstian and Maughan (*30*) had this to say: "Present indications are that the net result will mainly be the lengthening of the rotation by approximately five years, although it is too early to formulate definite conclusions."

At the present time research is being conducted on various phases of this problem by all the United States Forest Service Experiment Stations whose territory includes areas where the Nantucket pine moth is found. In addition, several state agricultural experiment stations and universities are engaged in similar research programs. There appears to be no practical method at the present time for the control of this insect on a large scale. For this reason, much work has yet to be done before the Nantucket pine moth problem is solved. This paper is an attempt to bring together the past and current work being done on this forest insect.

[1] In cooperation with the Georgia Forest Research Council and the Georgia Forestry Commission.

NOMENCLATURE

The Nantucket pine moth is a small lepidopterous insect belonging to the genus *Rhyacionia* of the family Olethreutidae. Synonymy for the Nantucket pine moth include the following: Comstock first described the species and assigned the name *Retinia frustrana* Comstock. In 1903 Fernald reclassified it as *Evetria frustrana.* In 1923 Heinrich (*24*) revised the classification of the North American moths of the subfamily Eucosminae of the family Olethreutidae. He retained the specific name and placed this species in the genus *Rhyacionia.*

The presently accepted common name for this insect is the Nantucket pine moth. The term "tip moth" is commonly used to apply to members of the genus *Rhyacionia* and closely related moths that inflict similar damage to host trees. For simplicity, the Nantucket pine moth will frequently be referred to throughout this paper as "tip moth."

Presently there are ten species of *Rhyacionia* known to exist in the United States. All have the same general habits and inflict injury by boring into buds and young stems of various pines. *Rhyacionia buoliana* (Schiff.) is the only species not native to this country. This European pine shoot moth, as it is commonly known, was first discovered in the United States in 1914.

Studies on the Nantucket pine moth have undoubtedly been made more difficult by the presence of various members of the genus *Rhyacionia* being found in association with *R. frustrana.* It is quite likely that these various species have been confused with the Nantucket pine moth in the reporting of some literature, because *R. buoliana*

(Schiff.), *R. busckana* Hein., *R. adana* Hein., and *R. rigidana* (Fernald) are all species of *Rhyacionia* known to occur within the Nantucket pine moth's range. The remaining five species, including *R. frustrana* var. *bushnelli* (Busck), are found in the western and midwestern parts of the United States.

In 1910, Swenk began observations of a pine tip moth injuring plantations in the Nebraska National Forest. Four years later Busck described this moth as a separate western species distinct from the eastern *frustrana* and gave it the species name *bushnelli.* Later, after several years of controlled rearing of *frustrana,* Heinrich succeeded in producing a typical *bushnelli.* This was done by inducing the smaller *frustrana* to oviposit on western yellow pine (*Pinus ponderosa* var. *ponderosa*). After rearing the insect on this tree, a comparison of the genitalia of several specimens convinced Heinrich that *bushnelli* was merely a local food plant race. He also states that there are no consistent characters upon which to separate the two. Busck's original name, *bushnelli,* was retained as a racial designation because of the great economic importance in some sections. The outstanding difference between this variety and *R. frustrana,* other than the range and larger adult size, is the overwintering habit. The *bushnelli* variety, prior to pupation in the fall, drops to the ground and pupates in the litter; the Nantucket pine moth overwinters in the young shoots of the host tree.

Literature referring to both *R. frustrana* and *R. frustrana* var. *bushnelli,* because of their similarities in habit and damage, is considered in this review.

DISTRIBUTION

Drawing on information from the National collection of the American Museum (Smithsonian Institution), Heinrich (*24*) found the tip moth distributed in Florida, Texas, Georgia, Alabama, South Carolina, West Virginia, Virginia, Pennsylvania, District of Columbia, New Jersey, and Massachusetts. Since Heinrich released this list, the species has been reported from North Carolina, Louisiana, Oklahoma, Mississippi, Arkansas, Tennessee, Ohio, Kentucky, Missouri, Illinois, Indiana, New York, Delaware, Maryland, Connecticut, and Rhode Island. Susceptible species of pine planted in any of these states are subject to tip moth attack. More generally this might include the range of shortleaf (*P. echinata* Mill.) and loblolly pine (*P. taeda* L.) in the South and the range of Virginia (*P. virginiana* Mill.) and pitch pines (*P. rigida* Mill.) in the Central and Northeastern states.

The Nantucket pine moth has been reported at Berthierville, Quebec (*15*). In 1942, however, Brown (*8*) indicated that this insect was misidentified and in reality was the white-pine shoot borer, *Eucosma gloriola* Hein. An undisputed record of Canadian occurrence indicates that the Nantucket pine moth was found in Simcoe County, Ontario, in 1944 (*38*). In this case, only a small population was found, but this report does indicate that the range of the insect extends into Canada. In all probability these are small populations restricted to the southern portions of Canada.

Bronson found through correspondence that this insect is not known to occur in northern New York, Vermont, New Hampshire, or Maine.[2] In view of the preceding Canadian report, the moth in all probability may be found in these states. Scarcity of suitable host material and cold weather undoubtedly limits the spread and reduces the population to a low level (fig. 1).

R. frustrana var. *bushnelli* has been recorded in Arizona, New Mexico, and Nebraska (*24*), in Minnesota, North and South Dakota (*10*), and, most recently, in Montana (*3*). It is believed that infestations located in Arizona and New Mexico were probably introduced on nursery stock coming from Nebraska.

HOSTS

Throughout the geographic range of the Nantucket pine moth there appears to be only one or two species of the genus *Pinus* not attacked by this insect. There is no record of attack on eastern white pine (*P. strobus* L.) or on longleaf pine (*P. palustris* Mill.). Two records of attack resembling tip moth damage on longleaf pine have been reported; however, these were not verified by collection and identification of the insect (*53*). For several years Wakeley carefully examined longleaf pine for tip moth injury but was never able to positively identify such damage.

Slash pine (*P. elliottii* var. *elliottii*) appears to share some of longleaf pine's resistance to attack by this insect (fig. 2). When attack does occur, it is usually restricted to the buds and generally creates very little injury, if any, to the developing shoots. Large amounts of resin accumulate on the outside of slash pine shoots where larval feeding

[2] Bronson, A. H. The Nantucket pine tip moth (*Rhyacionia frustrana* Comst.) and its occurrence on the Duke Forest. 1941. (Unpublished master's thesis. Copy on file Forestry Dept., Duke Univ., Durham, N. C.)

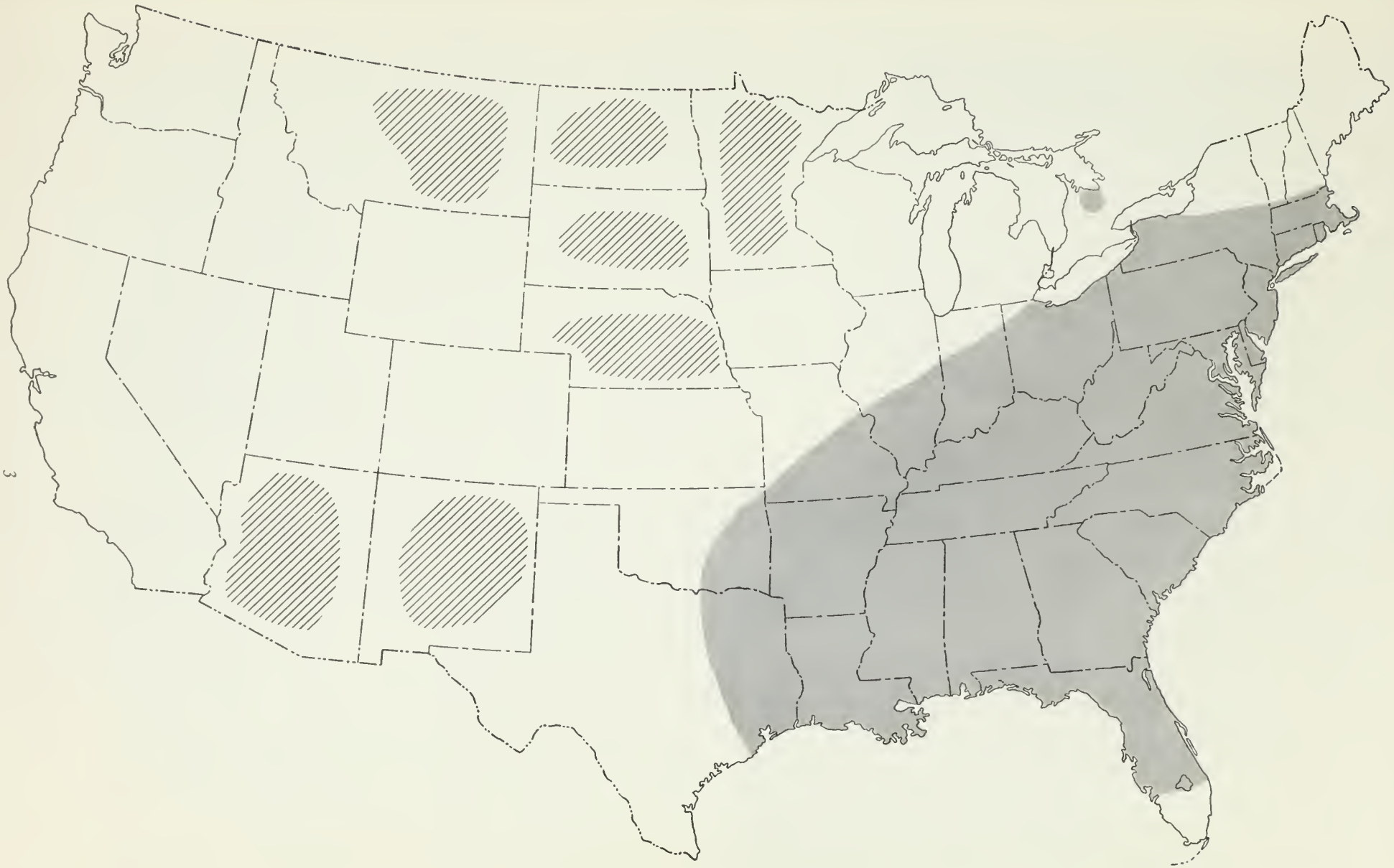

Figure 1.--Shaded area shows the general distribution of the Nantucket pine moth. Canadian observation is indicated by shaded circle. Cross-hatching shows states in which the bushnelli variety reportedly occurs.

Figure 2.--Severely injured loblolly pine growing adjacent to slash pine completely free of tip moth injury.

has occurred. Wakeley (*54*) states, "There may be a direct relation between the free resin flow of slash and longleaf pines and their resistance to tip moth attack." This free resin flow, along with the larger diameter of developing shoots in longleaf and slash pines compared with the smaller diameter of the heavily attacked species like loblolly pine and shortleaf pine, may very well be responsible for the difference in susceptibility and resulting injury. Although slash pine is generally not seriously attacked by the Nantucket pine moth, reports from Alabama in 1954 (*43*) indicated that approximately 1,000 slash pine were heavily infested. Such reports of heavy tip moth damage to slash pine plantations are not uncommon, but infestations are by far the exception rather than the rule.

Wakeley (*52*) has reported Nantucket pine moth attack on loblolly pine, shortleaf pine, ponderosa pine, Monterey pine (*P. radiata* D. Don), slash pine, sand pine (*P. clausa* (Chapm.) Vasey), spruce pine (*P. glabra* Walt.), and Sonderegger pine (*P. Xsondereggeri* H. H. Chapm.). This last species is a hybrid of longleaf pine and loblolly pine and is frequently damaged as seriously as its loblolly pine parent. Smith et al. (*42*) found pitch pine, Austrian pine (*P. nigra* Arnold), jack pine (*P. banksiana* Lamb.), ponderosa pine, and Scotch pine (*P. sylvestris* L.) all heavily infested in a Pennsylvania state nursery. Other reports include Japanese red pine (*P. densiflora* Sieb. and Zucc.), Japanese black pine (*P. thunbergii* Parl.), lodgepole pine (*P. contorta* Dougl.), Virginia pine, red pine (*P. resinosa* Ait.), and pond pine (*P. serotina* Michx.).

All species listed are subject to attack in varying degrees, but certain hosts are preferred in different parts of the United States. In the South and Southeast the favored hosts, by far, are loblolly and shortleaf pine. When both species are grown adjacent to each other they receive the same relative incidence of attack, but shortleaf pine appears to be the more seriously injured of the two species. Pitch pine, Virginia pine, and Scotch pine appear to be favored in New England and the Middle Atlantic States. In Nebraska the local food plant variety favors ponderosa pine and red pine over other species (*20*).

DESCRIPTION

The following descriptions do not go into any of the taxonomic details of these insect forms. They merely describe the insect in a general way to indicate size and appearance. More detailed descriptions of these forms can be found in the following publications: *17, 24, 33,* and *41.*

Adults

The adult moths are quite inconspicuous when at rest on foliage because of their small size. The wings are folded over the abdomen when the insect is not in flight; extended, the total wing span is 9 to 15 mm. At first glance, the adults are rather drab, but by closer examination the colorful details can be observed. The head, body, and appendages are covered with gray scales with the exception of the irregular brick-red and copper-colored patches on the forewings. These patches are separated by irregular bands of gray scales (fig. 3).

Sexual difference of the adults is readily determined by observation of the abdomen. The female abdomen is swollen in the middle and is apically pointed; the sides of the male abdomen are subparallel with a truncate apex. The inspection of the abdomen is quite reliable to determine sex of individual moths.

Figure 3.--Adult male Nantucket pine moth.

Both *R. frustrana* and *R. rigidana* are very often found occurring together in the field. Determination of the difference between the adults of these two species is very difficult. In general *R. rigidana* is a larger moth (18 mm. wing span), but reliable identification can be accomplished only by dissection.[3]

Eggs

Eggs are elliptical and measure approximately 0.85 mm. by 0.55 mm. When laid they are opaque and whitish, and in several days turn yellow to medium orange. Prior to hatching, they turn grayish. At this time the dark head capsule and the slight movements of the developing larva can be seen through the egg chorion. Eggs are generally laid singly; however, groups of two or three eggs are sometimes encountered (fig. 4).

Larvae

The first instar larvae are very tiny, cream-colored caterpillars approximately 1.5 mm. long. The head and thoracic shield are black. The body is sparsely covered with minute hairs that are barely visible even under a hand lens. The last instar larvae are light brown to orange in color and grow to approximately 8 mm. in length.

Two workers have attempted to determine the number of larval instars this insect passes through. Mortimer (*34*) was unable to distinguish more than two instars, but stated that a third may possibly occur after the larvae have tunneled into the shoot. Actual head capsule measurement of the *bushnelli* variety indicated six groups (*19*). Although these exhibited much variation, which was attributed as possibly a result of food source, they concluded that this insect went through a series of six instars. Variations of measurement in the past might well be caused by any one, or a combination, of the following: differences in food source, difference in sex, or different species of *Rhyacionia* all thought to be *frustrana.* In any event, more than three instars occur.

Except for the crochets possibly being slightly more numerous on *R. rigidana,* there are no satisfactory characters to separate the larvae from *R. frustrana* (*33*).

Pupae

Pupae are approximately 6 mm. in length. When first formed they are light brown in color and become darker as they mature. Just prior to emergence of the adults, variations in the wing coloration can be detected through the pupal skin.

The female pupae are reported to have the two genital openings confluent on the eighth abdominal segment, whereas the single male genital opening is situated on the ninth segment.[4]

[3] Clarke, J. F. G. Personal correspondence. U. S. Natl. Mus. 1959.

[4] Bronson, *op. cit.*

Figure 4A.--Series of five tip moth eggs laid on loblolly pine shoot by caged adult.

Figure 4B.--Tip moth eggs laid on developing loblolly pine shoot.

LIFE HISTORY

Life Cycle

The Nantucket pine moth spends the winter months as a pupa within the injured tips (fig. 5). (One early reference indicates a full grown larva was found during February, indicating possible occasional larval hibernation (*9*).) In Nebraska, the mature larva of the *bushnelli* variety drops to the ground and overwinters as a pupa in the litter (*19, 49*). Such a habit possibly accounts for the survival of these overwintering forms during the cold winter months experienced in this area.

On warm, sunny days in early spring, adults begin to emerge from the tips. In the southern part of the United States, adults can be found in the field as early as January. By circular movements of the abdomen and with the aid of a series of abdominal spines, pupae are able to work part way out of the infested tips. Here the adult is free to emerge without injury and leaves the empty pupal case projecting from the tip.

The preoviposition period is considered to be short. It is during the hours of dusk and darkness that mating and egg laying occur. Mortimer reports that during the evening the moths fly around the trees depositing their eggs, and that eggs were found in most instances 2 days after adults had emerged (*34*). These eggs may be found on the new or old growth needles, the developing tips, or on the buds. In Virginia (*50*) it was found that a majority of the eggs were laid in the axils of the needle and the stem.

Egg incubation varies with weather conditions. It is particularly affected in the spring when cool weather is apt to occur after egg deposition. Such a condition would cause prolonged incubation. In Tennessee, the first spring generation egg period has been recorded as long as 31 days (*34*). During this time the weather was cool and damp. The second and third generation egg periods for the

Figure 5.--Injured loblolly pine shoot dissected to expose overwintering pupae.

above mentioned season were 18 and 9 days, respectively. At Durham, North Carolina, during the spring of 1941, first generation eggs hatched in about 2 weeks.[5]

The developed larva chews its way out of the egg, leaving the egg chorion still secured to the plant. The first instar larva begins to migrate about the shoots looking for a suitable place to feed. Shortly, a delicate web is constructed in the axil formed by a developing needle and the stem. At first, evidence of the presence of tip moth larvae on developing shoots is quite unnoticeable. The small webs constructed by the young larvae can only be detected by close inspection of individual shoots or buds. Here the larva bores into the needle sheath and feeds on the needles. Early injury may consist of only one dead needle which has been severed by the feeding of the larva in the sheath of the needle fascicle. In addition, some external feeding on the stem occurs.

[5] Bronson, *op. cit.*

Mortimer (*34*) found that during the second instar the larva spins a new and larger cell-like web between buds or the buds and needles. After consuming this bud, the larva migrates to other buds on that shoot or moves to entirely new shoots. Recent unpublished studies by other workers confirm larval migrations; most older publications indicate that the larvae begin boring into the shoots or buds almost immediately and carry out no such extensive migrations about the host plant.

As the insect develops, fecal material and resin exuded from these lesions begin to accumulate on the outside of the tips. Eventually the mining of the larvae severs the conductive tissue of the tip and the affected portions turn brown. This browning is quite conspicuous at considerable distance. In many cases it is the first evidence of injury noticed by the untrained observer.

Larvae generally continue feeding within the shoots and buds once they have begun boring into these tissues. The succulent bud appears to be the most attractive portion of the shoots. Once this has been consumed, larvae begin boring down the center of the young stem. It is not uncommon to find more than one larva feeding in a single stem. In the case of heavy infestations this might run as high as 10 larvae. The entire larval period lasts 2 to 4 weeks. Prior to pupation, a webbed cell is constructed within the injured shoot.

Generations Per Year

A series of experiments were conducted during 1929-1930 to establish whether the tip moth had overlapping broods in the South or went through successive generations (*54*). Evidence indicated successive generations. Depending on the geographic location, the life cycle is known to be repeated one to four times during the growing season. However, recent work indicates that in the extreme South there may be as many as five generations during this period. Possibly a sixth generation might occur in some sections during a very favorable season.

Wakeley reports (*54*) that there are four successive generations per year on young pines of susceptible species in southeastern Louisiana. This appears to hold true for most of Texas, Oklahoma, Mississippi, Alabama, Georgia, and Florida. The southern portions of the Gulf States may very well experience more than four generations per year. Areas in North Carolina,[6] Tennessee (*34*), and Virginia (*50*) are reported to have

[6] Bronson, *op. cit.*

three generations; two generations are reported in Ohio (*37*) and Pennsylvania (*42*). This also applies to the areas north of these two states. A number of workers studying the tip moth have recorded the adult emergence periods (fig. 6).

DAMAGE

Damage caused by the Nantucket pine moth can be regarded in four categories: deformation of the host tree, loss or retardation of height growth, reduction of cone crops, and in severe instances, mortality of infested trees (fig. 7).

Tree Deformation

The ability of the trees to recover from terminal injury without any serious crooking is dependent on the production of new buds from needle bundles as well as the vigor of the tree. In general, the more prolific the tree is in producing such buds, the better its recovery from tip moth attack.

Where tree vigor is sufficient, new buds are produced, and attacked trees readily recover. Where tree vigor is insufficient or where the leading shoots are continually attacked by tip moths, all of the uppermost lateral branches may compete for dominance and cause a multiple- or crooked-stemmed tree. In some cases recovery of trees from insect attack results in a crooked rather than a straight stem. This ability of attacked trees to make a good recovery may be an inherited characteristic.

Loss or Retardation of Height Growth

At present no one is able to give more than an estimate of the final effect of tip moth damage on the host tree. Past study indicates that significant difference in height growth occurs between protected and unprotected trees during the early years of growth. Yet, what is not known is how much difference will exist when the trees are of a merchantable size. Such knowledge would indicate to what extent control operations were economically feasible.

Site appears to influence to a great extent the severity of damage tip moth inflicts on the host trees. Generally, the better suited a tree species is to the site, the less severe the injury. Wakeley observed (*53*) that loblolly pine planted on sites best suited for longleaf pine were so seriously killed back by tip moth that they were overtaken by

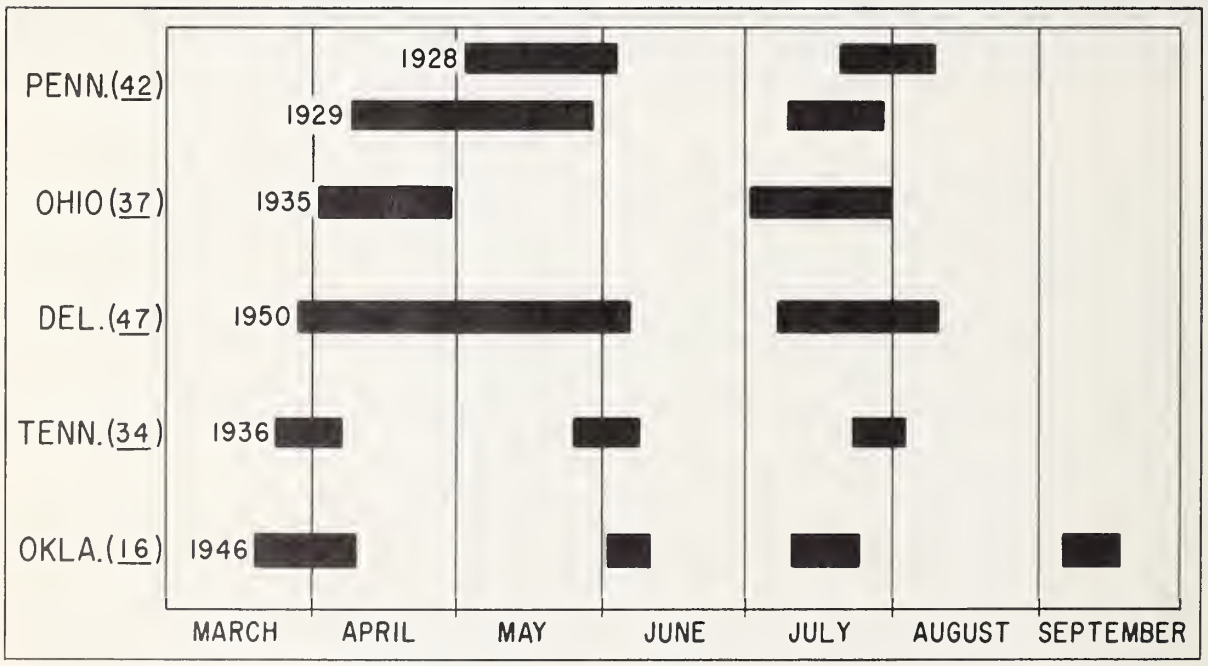

Figure 6.--Adult emergence periods as reported by various investigators for different states. These emergence periods illustrate in most cases only one season and may vary from year to year, depending on local weather conditions. Horizontal lines show span of the adult emergence for year indicated.

Figure 7A.--Crooking of the main stem of a loblolly pine caused by the repeated attack of tip moth.

Figure 7B.--Forking of the main stem of a loblolly pine caused by tip moth attack of the terminal leader.

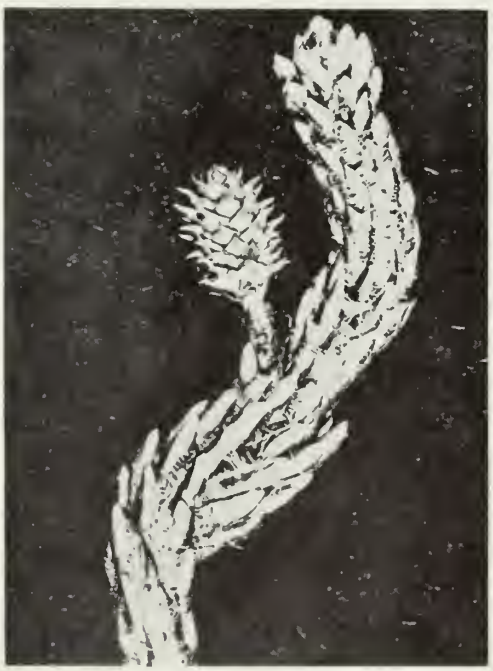

Figure 7C.--Young shortleaf pine shoot with female flower that has been attacked by tip moth. Initial attack has caused bending of the growing shoot. Subsequent feeding will sever the conductive tissue and cause death of the shoot and female flower.

Figure 7D.--Young loblolly pine killed by severe and repeated attack by tip moth.

natural longleaf reproduction in 10 years. On deeper and more penetrable soils, possibly only a few feet away, the loblolly made much better growth in spite of tip moth attack. The influence of site on the severity of tip moth damage can also be observed along the sides of roads and highways. Road grading and the action of erosion have in some cases completely removed topsoil and left bare mineral soil. Reproduction found growing in these areas is very often so severely damaged annually that death results (fig. 8).

Two types of injury were located on trees infested with tip moth in Pennsylvania (*42*). "On host species having large buds and heavy growth, the injury is confined to the buds, while on species with small buds and weak growth the tips of the twigs as well as the buds are hollowed out." This same observation may be made between slash pine and loblolly pine in the South. Slash pine, when attacked, generally sustains injury to the buds and only when severely attacked are the terminal shoots injured. Loblolly pine, on the other hand, commonly has the shoots as well as the buds completely mined out.

The effect of repeated attacks on the growth and dominance of loblolly pine seedlings was measured on released trees in North Carolina (*55*). On the basis of the number of years a seedling was attacked, it was found that each year of attack reduced seedling growth by 0.5 foot for three successive years.

Merkel in 1955[7] and Mason in 1958[8] both reported on the effects of tip moth on growth loss in the Southeast. Throughout the summer, various formulations of insecticides were used to control tip moth infestation on the test trees. The results Merkel received in the Piedmont of South Carolina indicated that protected trees averaged 0.43 foot greater in height than the check trees. This proved to be statistically significant, but prac-

[7] Merkel, E. P. Studies on control of the Nantucket pine moth in relation to growth loss. U. S. Forest Serv. Southeast. Forest Expt. Sta. Unpublished Preliminary Res. Note. 1955. (Mimeographed, 2 pp.)

[8] Mason, R. T. Study of tip moth effects on height growth in loblolly pine plantations: Two year results. Hiwassee Forest Res. Note 3, Calhoun, Tenn. 1958. (Mimeographed, 2 pp.)

Figure 8.--Severely damaged loblolly pines growing along badly eroded roadside.

tically speaking appeared to be small. In southeastern Tennessee, Mason found a significant difference of 0.41 foot in reduced growth on unprotected trees in 1956. However, results of the 1957 season were not significant at all; in fact, the unprotected trees grew an average of 0.08 foot more than the protected trees. A similar observation was made by Wenger (*56*) in 1955. Tip moth-infested loblolly pine seedlings showed greater height growth than uninfested seedlings. Infested 2-year-old seedlings showed growth in height of 0.32 foot more than the uninfested seedlings. A similar difference of 0.45 foot was observed with 4-year-old seedlings. Both of these differences were found to be significant, and no plausible explanation for this behavior could be advanced.

At Mississippi State College (*36*) the growth differential for protected loblolly pine was very significant. The average difference was recorded for both upland and bottom land sites and amounted to 12.4 inches and 20.9 inches, respectively. Terminal attack was completely controlled on the treated trees by spraying six times during the growing season at intervals of 10 days to 2 weeks. This spraying practice can hardly be recommended on any basis other than experimental, but it did demonstrate the increased growth that could be expected in these areas if tip moth were completely controlled.

Some of the height difference between 23-year-old loblolly and shortleaf pines in northern Mississippi was attributed to early tip moth damage (*57*). After 13 years growth, loblolly pine averaged 34 feet in height and shortleaf pine 23 feet in height — at the end of 23 years the average heights were 63 and 48 feet, respectively. It was observed that this insect attacked and killed back the leaders of shortleaf far more severely than those of loblolly.

The repeated killing of the growing shoots by each successive generation of this insect is believed by some workers to significantly cut down the growth of the injured tree (fig. 9). Although limited studies of 1 to 2 years have been conducted, no one has yet proven the over-all effect of tip moth attack over a long period of time. In the fall of 1958, the Southern Forest Experiment Station[9] started a research study to determine the over-all difference in growth between protected and unprotected trees over a 30-year period, using both loblolly and shortleaf pines.

[9] Beal, R. H., and Orr, L. W. Evaluation of tip moth injury in relation to growth of loblolly and shortleaf pine. South. Forest Expt. Sta. Work Plan. 1958. (Mimeographed, 11 pp.)

Figure 9.--Loblolly pine leader showing multiple injury by tip moth. Swollen needle fascicles just below injury, such as the ones outlined in white, are new buds developing.

At the completion of the study it is hoped that this basic question "Just how much damage does tip moth actually cause?" will be answered. At present this question will receive a variety of answers from persons who have worked with the insect. These will include the extremes of "no damage" to "increasing the rotation by five or more years." It must be remembered that the degree of tip moth damage in one area is not necessarily the same as the degree of damage occurring elsewhere. This also applies to different species of trees which are attacked with different degrees of severity. Therefore, such divergent answers are undoubtedly valid when they are applied to certain areas.

Reduction of Cone Crops

The increasing need for good quality forest tree seeds has stimulated the development of seed orchards in many areas. These open-grown seed orchards provide ideal conditions for tip moth development. When trees are first set out in fields, tip moth damage may very well affect early survival. Zak (*58*) states that tip moth injury in seed orchards may, after the first or second year, promote the desirable characteristic of a full and bushy crown. When the trees begin producing cones, however, attack may prove to be a hindrance and reduce seed yields by destroying terminal buds containing embryonic flower buds. Another point to be considered is the availability of suitable grafting tips. It is highly desirable that undamaged tips are available for grafting of the superior scions to stock trees.

Tip moth attack is generally restricted to pines less than 15 feet in height. Many accounts, however, have reported trees of much larger size being attacked. Such tip moth injury could be responsible for the reduction of cone crops on mature trees.

In 1957 (*45*), parts of northern Mississippi, Louisiana, and Texas reported severe infestation of tip moth on commercial size trees. From the air the red-fringed crowns appeared dead, as if killed by bark beetles. This attack is not always as easily recognized on large trees. In most cases only scattered tips are attacked and recognition of this injury from the ground requires careful observation.

Tree Mortality

Possibly the most serious damage caused by the Nantucket pine moth ever reported was in 1876 when the presence of the insect was first recorded. Scudder (*41*) observed large numbers of 20- to 30-year-old pitch pines on Nantucket Island that were dead and dying of an unknown cause. During the War of 1812, the inhabitants of Nantucket Island, in an effort to obtain an adequate fuel supply, had denuded the island of every tree. For many years following, the island remained barren. Finally, plantations of pitch pine were set out to reforest the area. Mortality began to appear when the trees were 10 to 20 feet tall (*39*). Examination of these trees led Scudder to believe that mortality was caused by a terminal-feeding Lepidoptera, later named the Nantucket pine moth. This is the only reference in the literature that reports widespread killing caused by *R. frustrana*.[10]

There are other reports of possible tree mortality as a result of tip moth attack (*19, 21, 34, 44*); however, when killing occurs, it is usually restricted to trees growing on very poor sites. In these cases possibly the site condition contributes as much to the death of the tree as the insect. In western Florida, severe tip moth infestations caused high mortality of Monterey pine the second and third years after planting. Although adjacent native pines were also heavily attacked, they demonstrated a capacity to survive (*44*).

CONTROL

Scudder, in 1883 (*41*), suggested three controls for the tip moth on Nantucket Island. They inincluded building bonfires at night to kill egg-laden adults attracted to the light, and the collection and burning of all infested tips on the island. (Although many references mention the practice of hand picking infested tips for control of tip moth, the Great Southern Lumber Company in Louisiana gave up such a control operation after two seasons of unsuccessful attempts (*54*).) Scudder's third proposal was to cut down every tree and seedling on the island to eliminate the food source of the insect!

Chemical Control

Most of the early chemical control work on the Nantucket pine moth was influenced by control work on the introduced European pine shoot moth. Howard (*26*) reported in 1925 that a 2-percent nicotine dust was very effective in killing the adults of the *bushnelli* variety of tip moth. In 1936 Baumhofer (*5*) reported on the prevention of tip moth introduction from nursery stock into isolated plantations. He advocated dipping 2-year-old seedlings in formulations of both white oil emulsion and nicotine oleate for consistent kills of the eggs without any injury to the trees. This treatment was not effective against seedlings that contained larvae or overwintering pupae within the tips. It was recommended that injured seedlings that contained larvae or pupae in the tips

[10] In view of the absence of such widespread mortality since this first report, there is some question that the Nantucket pine moth was the major factor causing this mortality. It is conceivable that low winter temperatures or salt spray could have caused severe weakening of these exposed trees and been the primary factor responsible for mortality.

should be cut off one inch below the injured portion. Both dipping and cutting off the injured tips were considered necessary when eggs, larvae, or pupae were apt to be present on the seedlings.

During the middle and late forties DDT became available for experimental use. This led the list in the development of the great number of organic insecticidal compounds now available. In 1946, DDT was tested for the control of tip moth in Oklahoma (*2, 16*), and formulations as low as 0.118-percent DDT were found to be effective. Infestation in sprayed plots averaged 9 percent compared to 74 percent in the check plots.

In Delaware, Stearns (*47*) worked on a chemical control for both the Nantucket and European tip moths. This task was complicated by two emergence periods for the Nantucket pine moth and one emergence period for the European pine shoot moth. Blackleaf 40, lead arsenate, BHC, parathion, and DDT in various formulations were all tested. Parathion and DDT were the only insecticides that gave reliable control of both species. The final recommendation called for a spray at each peak emergence, and one 14 days prior to, and one 14 days following emergence. This schedule necessitated a total of nine different sprays during a single season.

In 1955, one percent DDT or one percent BHC, formulated in either emulsions or suspensions, were the only insecticides that gave nearly 100 percent protection from tip moth at Union, South Carolina.[11]

Tip moth is prevalent in forest tree nurseries. To cut down the loss of shippable seedlings and prevent the distribution of infested nursery stock in Virginia,[12] tests were conducted using periodic applications of DDT at the rate of 1 pound per acre. Tip moth infestation was reduced to less than one in five thousand seedlings with the correct timing of three spray applications during the growing season. Because of the small size of developing seedlings in Virginia nurseries, tip moth was not found to attack prior to August.

Where control of tip moth has been unsuccessful on nursery stock, fumigation offers some possibility in preventing the distribution of the insect. Fumigation with 5 ounces of sodium cyanide per thousand cubic feet of space for a period of 1 hour has given satisfactory results (*6*).

One of the big objections to chemical control of tip moth is the problem of getting into plantations with spraying equipment. Aerial spraying would eliminate this difficulty. However, Stearns (*47*) states that results of aerial application of DDT in 1949 could only be described as most disappointing. This aerial treatment had no measurable effect on tip moth populations in an 11-year-old loblolly pine plantation.

Recent efforts have been more successful in obtaining control by this method. In 1958, aerial spray tests were conducted in both Mississippi (*36*) and east Texas (*7, 46*) by separate workers. Both operations were timed to coincide with the peak emergence of the adult moth. The east Texas operation was aimed at killing the moths, and it appeared that adult mortality was adequately accomplished. Workers in the area prior to spraying observed numerous moths flying about the plantation, but following spraying no moths could be found in flight. Both DDT and chlordane were applied at the per acre rate of 2.5 pounds actual material in 2.5 gallons of fuel oil and 5 pounds actual material in 5 gallons of fuel oil. Only DDT demonstrated any effective control. As a result of this one spray application in the spring, the DDT-sprayed loblolly pines grew in height nearly three times as much as the check trees. In spite of good control during the first generation (0 and 2 percent leader infestation for the two rates of aerially applied DDT), leaders were over 90 percent infested by the following October on these two areas. Such a rapid increase of the insect during the remainder of the summer season can be attributed to either migration into the area or a very high biotic potential.

In Mississippi (*36*), DDT, malathion, and guthion were all applied from the air as well as by mist blower from the ground. These were applied using 3 gallons of water emulsion per acre at 2, 1.5, and 0.5 pounds actual material per acre, respectively. The results of the April and June spray operations showed no significant difference between treatments. The third application in July indicated that the treated areas were significantly better than the check area. This difference was attributed to two factors. Heavy rains following the April and June applications may have been responsible for washing away the residual spray on the trees. No such rains occurred after the July application. Another factor might have been the application of the July spray at a later time after peak emergence of the adults.

Timing of insecticide sprays is of utmost importance to obtain an effective kill. Because the spray in most cases is directed at the larvae, the most desirable time for spraying is when the

[11] Merkel, *op. cit.*

[12] Morris, C. L. Chemical control of Nantucket pine tip moth (*Rhyacionia frustrana*) in forest nursery stock. Va. Div. Forestry. 1956. (Typewritten report, 5 pp.)

developing larvae chew their way out of the egg chorion and migrate to a suitable place for feeding.

Insecticidal control of the tip moth has been quite effective using such compounds as DDT and BHC, but the need for two to four applications per year and the inaccessibility of areas to spraying equipment makes such controls far from economical on a commercial basis. Results from airplane spraying in the past have been inconsistent, though the method appears promising and is still being tested by various workers. The development of new insecticides possessing longer residual characteristics and of systemic insecticides provides new compounds that might well be adapted to aerial application. Because of the high application cost and the rapid build-up of this insect, spray treatment with insecticides is presently not recommended for control of tip moth in plantations except where high value trees are involved.

Silvicultural Control

The ultimate goal of forest insect research should be the control of obnoxious insects through forest management practices. Past observations indicate that tip moth damage in natural regeneration is slight with a low incidence of occurrence. Yet, when plantations of favored host trees are established, incidence of tip moth in most cases is very high and causes varying degrees of damage. Presently all the factors involved in these observations are not known or thoroughly understood.

In spite of the great interest in silvicultural control, comparatively little work has been conducted in this field. Investigators who advocate silvicultural practices to control other insects, such as the white pine weevil, have studied the effect of various cultural practices on weevil incidence. These include spacing studies, the use of mixed stands, shading, and the planting of less susceptible species in high risk areas. With more intensive forest practice and the limitations of insecticides against this insect, interest is being shown in this field. It is very likely that more work in this direction will be carried out in the future and less effort will be made to control tip moth in plantations through the use of chemical insecticides.

A comparison of tip moth infestation in the upper and lower branches has been made by several workers. Results indicate that tip moth incidence on the upper half of trees was much higher than on the lower half of the tree. One conclusion was that perhaps the grass level acted as a protective barrier. Beal et al. (*6*) states that grasses, such as broomsedge, may offer some protection to young seedlings and the lower portions of the larger size classes of reproduction. This also was proposed as a possible explanation for the comparative freedom from attack of young pines in the Nebraska National Forest (*19*). Another explanation might be that the more succulent shoots, apparently favored by the tip moth, are found on the upper branches of the trees.

Wakeley (*54*) states that there is definite evidence that growing trees in dense stands minimizes tip moth damage. This was demonstrated by a spacing study in Louisiana which revealed that tip moth attack is more intense at the wider spacings (*22*). The beliefs that grasses offer some protection from tip moth and that moth incidence is less at the closer spacings seem to indicate that shading might be a very important factor affecting tip moth attack. Harrington (*23*), however, concluded from work done in Texas with loblolly pine that tip moth incidence was not significantly related to shading.

Another study indicated that incidence of tip moth attack was 74 percent for loblolly pine reproduction released from hardwood cover as compared to 64 percent attack for control seedlings (*55*). This overhead release apparently exposed the trees to more frequent attack. Huckenpahler (*28*) found loblolly pine the best species in northern Mississippi, despite tip moth and pine webworm attack. Tip moth attack of loblolly pine in this area was 82 percent on released and 28 percent on the unreleased stands. This same worker found that tip moth incidence among pines planted under deadened low-grade hardwoods on oak ridges in Mississippi was greater on the released plots than on the unreleased plots (*27*). Here again the indication is that some form of shading, either mutual or by other species of plants, significantly decreases the attack by tip moth.

In certain areas workers have resorted to substituting highly resistant tree species for species seriously damaged by tip moth. Japanese black pine has been successfully used in Oklahoma (*1*), on Nantucket Island (*29*), on Long Island (*32*), and along the North Atlantic coast. Although this species is subject to attack by tip moth, it is less susceptible to serious injury than other tree species indigenous to these areas. A similar substitution is being made in the South. Very often the highly susceptible loblolly pine is being replaced by the more resistant slash pine or longleaf pine. Where slash and longleaf pine are not suitable for planting, damage can possibly be reduced by confining the more heavily injured species, such as loblolly and shortleaf pines, to favorable sites, in mixture with resistant species, at close spacing, or started in brush.

Control Through Tree Breeding

Tree breeding appears to offer some hope in the problem of tip moth. Study of trees or races of trees which appear to recover best from tip moth attack or are apparently resistant to attack might indicate some physiological factor that creates an unfavorable condition for the insect. A characteristic to be desired in the breeding of tip moth-resistant pines is ability to grow rapidly. This is particularly true during the early years of the tree's growth. Secondly, the tree should be able to develop dormant buds readily.

It is very unlikely that a race of some susceptible species of pine, such as loblolly pine, exists that is distasteful to the tip moth. A search for variations within one species of pine has been rather disappointing. In 1954, a local geographic seed source study was started using loblolly pine seed from four areas in Louisiana and Arkansas. Crow found in 1956 (*11*) and 1958 (*12*) that percent tip moth damage was high on all seed sources and showed no significant variation. Similar data on tip moth were collected from southwide pine seed source study plantations (*25*). Although efforts thus far have been futile, the possibility still exists that a tip moth-resistant strain may be found.

Natural Control

Parasites of the Nantucket pine moth have received a great amount of attention in the past, undoubtedly prompted by the large number of parasites known to attack the tip moth. In spite of many species of parasites, both indigenous and introduced, tip moth has rarely been known to be controlled satisfactorily by these agents though varying degrees of control have been recorded. The first reference to parasitism of tip moth was published in 1883 (*41*). It mentioned three undetermined parasites that were found associated with the tip moth, but none seemed sufficiently abundant to exert a continued controlling effect.

Possibly the most classic example of the effect of parasitism occurred in the Nebraska National Forest (*13, 51*). Ponderosa pine in this area was being so severely injured that the discontinuance of planting this species was seriously considered. In 1924 an attempt was started to control the *bushnelli* variety by means of parasites. A preliminary study was made at Falls Church, Virginia, to learn what eastern species were available for introduction into the Nebraska National Forest. A total of twenty-one species of parasitic Hymenoptera and two species of parasitic Diptera were reared from a large quantity of tip moth-infested tips. In addition, a small lot of material received from Bogalusa, Louisiana, produced six species of parasitic Hymenoptera. Of the Virginia parasites liberated in 1925, only one was recovered, (*Campoplex frustranae* Cushman), but this species was so effective that the planting of ponderosa pine continued. Injury to terminal shoots in the area was reduced from 90 percent to 15 percent within 4 years after parasite introduction.

In spite of the presence of twenty-three different species of parasites, less effective control was recorded from 1930 to 1933 in the vicinity of Richmond, Virginia, where parasitism has ranged from 5 to 57 percent (*50*). In North Carolina (*6*), only slightly more than 7 percent of the overwintering pupae were parasitized. In this same area, however, as many as 40 percent of the tip moth eggs examined were parasitized by an unidentified egg parasite. In all probability it was *Trichogramma minutum* Riley, a Hymenoptera recorded by several workers as an egg parasite of tip moth.

In addition to parasites, a number of birds and predatory insects are enemies of the tip moth. It is not unusual to find birds tearing open tip moth-damaged shoots in search of the larval and pupal forms. However, birds can hardly be classified as very effective controls. Predatory insects, on the other hand, might have a great effect on tip moth populations. Unfortunately, little or no work on these predatory insects has been conducted and reported in the literature.

There are a great number of known parasites that attack the Nantucket pine moth. The following is a list of the known parasites of the genus *Rhyacionia* occurring in the United States. This is not necessarily a complete list but represents a large majority of the known species. Those preceded by an asterisk (*) have been reported as attacking the Nantucket pine moth.

Known parasites of the genus Rhyacionia compiled from the following references: 4, 13, 14, 18, 31, 35, and 40 .

Order Diptera

Family Tachinidae

**Lixophaga mediocris* Ald.

**Lixophaga plumbea* Ald.

Order Hymenoptera

Family Braconidae

Macrocentrus instabilis Mues.

Orgilus obscurator (Nees)

Agathis binominata Mues.

**Agathis pini* (Mues.)

Apanteles bushnelli Mues.

**Microgaster epagoges* Gah.

**Phanerotoma rhyacioniae* Cush.

**Bracon gelechiae* Ashm.

**Bracon gemmaecola* (Cush.)

**Bracon mellitor* Say

Bracon politiventris (Cush.)

**Bracon rhyacioniae* (Mues.)

Bracon variabilis (Prov.)

Family Ichneumonidae

Scambus aplopappi (Ashm.)

**Scambus hispae* (Harr.)

**Calliephialtes comstockii* (Cress.)

Pimpla turionellae (L.)

**Itoplectis conquisitor* (Say)

Itoplectis evetriae Vier.

Itoplectis 4-cingulatus (Prov.)

**Glypta varipes* Cress.

**Campoplex frustranae* Cush.

Zaleptopygus retiniae (Cress.)

**Cremastus epagoges* Cush.

Cremastus evetriae Cush.

Cremastus interruptor Grav.

Cremastus rhyacioniae Cush.

Family Trichogrammatidae

**Trichogramma minutum* Riley

Family Eulophidae

Tetrastichus longicorpus (Gir.)

**Tetrastichus marylandensis* (Gir.)

Tetrastichus turionum (Htg.)

**Tetrastichus varicornis* (Gir.)

**Elachertus pini* Gah.

**Hyssopus rhyacioniae* Gah.

**Hyssopus thymus* Gir.

**Euderus subopacus* (Gah.)

Family Elasmidae

**Elasmus setosiscutellatus* Cwfd.

Family Encyrtidae

**Copidosoma geniculatum* (Dalm.)

Family Eupelmidae

**Eupelmus cyaniceps amicus* (Gir.)

Family Perilampidae

**Perilampus chrysopae* Cwfd.

**Perilampus fulvicornis fulvicornis* Ashm.

Perilampus tristis Mayr.

Family Pteromalidae

**Catolaccus aeneoviridis* (Gir.)

**Habrocytus thyridopterigis* How.

Family Eurytomidae

Eurytoma appendigaster (Swed.)

**Eurytoma tylodermatis* Ashm.

Family Chalcididae

**Haltichella rhyacioniae* Gah.

Haltichella xanticles (Wlkr.)

**Spilochalcis flavopicta* (Cress.)

Family Bethylidae

**Goniozus electus* Fouts

Goniozus longiceps Kief.

Goniozus longinervis Fouts

Efforts to control tip moth infestations using parasitic agents in the past have been limited to their introduction into an area. Percent parasitism has been found to vary considerably from year to year and from generation to generation. In the future, breeding large quantities of selected parasites and releasing these parasites at the most advantageous time in tip moth-infested plantations may prove less costly and more effective than chemical controls.

In 1910, Swenk (*48*) reported evidence of an entomophilous fungus that had been at work in Nebraska. Unfortunately, this is the only record of any such agent occurring naturally. As far as can be ascertained such a fungus had never been isolated or identified. However, the possibility of the presence of either a virus or bacterium that is lethal to the Nantucket pine moth is receiving much interest. This interest has been stimulated by success obtained in microbial control of other insects.

SUMMARY

The Nantucket pine moth, *Rhyacionia frustrana* (Comst.), is generally considered a major forest insect. This insect is found throughout the eastern United States; its range extends from eastern Texas and Oklahoma north to Ohio and eastward into southern New Hampshire. One report indicates the moth occurs in southern Canada. This "tip moth," as it is commonly referred to, attacks the growing shoots of almost all native and introduced pines. Longleaf pine and eastern white pine are the only species which appear to be immune to such attack.

The body and appendages of the small adult moths are covered with gray scales. Irregular brick-red and copper-colored patches appear on the forewings. In the spring of the year, the adults emerge from the overwintering pupae and lay their eggs on the buds, new needles, and developing shoots. The developing larvae bore into this growth; subsequent feeding causes death of the new growth. Pupation occurs within the dead shoot. Depending on local weather conditions, there are one to five generations each season.

Attack by the Nantucket pine moth is most severe in young plantations. Damage inflicted on the host tree can be regarded in four different categories. They include tree deformation, loss or retardation of height growth, reduction of cone crops, and in severe instances, tree death. It has been found that all four of these injuries occur in different degrees; however, the economic significance of such injuries have not yet been established.

Effective control of this insect can be accomplished by the application of insecticides by hydraulic sprayers. Some success has been obtained by aerial application. Except for high value areas, insecticidal control procedures cannot be recommended because of economic considerations. The

relatively small amount of work conducted in silvicultural control indicates that growing trees in dense stands minimizes tip moth damage. Growing susceptible pines under hardwood cover also minimizes injury. In areas where certain species are severely attacked, such trees have been replaced by species not so seriously damaged. Efforts to find highly resistant or immune trees thus far have been futile. Continued search for such trees and tree breeding may result in the discovery or development of a strain that will be highly resistant to tip moth injury. In the field of natural control, considerable work has been done on the parasites of this insect. In spite of the great number of known parasites and the fairly high percent parasitism, these agents do not appear to affect to any great extent tip moth populations and subsequent injury.

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